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Aerojet-General CORPORATION

AZUSA, CALIFORNIA

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INFORMAL REPORT OF PROGRESS

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27 March 1962

TO: Bureau of Naval Weapons
Director, Special Projects (SPN)
Washington 25, D. C.

Attn: Code SP-271

VIA: BuWepsRep, Azusa, California

SUBJECT: Development of Improved High-Strength Preimpregnated Materials for Filament-Wound Rocket Motor Cases

PREPARED UNDER: Navy, Bureau of Naval Weapons Contract NOw-61-0642-c(FBM)

PERIOD COVERED: 1 January through 28 February 1962

This is the sixth in a series of informal progress reports submitted in partial fulfillment of the contract.

AEROJET-GENERAL CORPORATION

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NOTE: The information contained herein is regarded as preliminary and subject to further checking, verification, and analysis.

ABSTRACT

Lot 7 dry roving and Lots 2, 4 and 5 prepreg have been evaluated for strand tensile strength and NOL ring tensile strength. Lot 7 was 20E roving with approximately 408 filaments per end and was finished with "HTS" sizing. Standard 20E roving has 204 filaments per end. The average strand tensile strength for this lot was 334,800 psi and the average NOL ring strength was 322,800 psi. These values were very similar to the strength values for previous experimental lots of roving and no advantage in strength was indicated by the fiber of smaller diameter. However, an 18-in.-dia chamber fabricated from this material appeared very uniform and had an unusually smooth surface. Lots 4 and 5 prepreg had strand tensile strengths of slightly over 320,000 psi and NOL ring strengths of 336,000 psi and 349,000 psi respectively. As with the other prepreg lots, the NOL ring strength is between 5 and 10% higher than the strand strength. The opposite is true of the dry glass where the strand strength has been higher than the NOL ring strength in all cases.

A curvilinear mathematical model used in the statistical analysis of dry glass strength data developed from the Aerojet strand test has accounted for 75% of the strength variation. As was true with the linear model tried originally, weight per yard and fuzz content are the most significant variables to be controlled in obtaining higher tensile strengths. Due to the delay in arrival of the last few lots of material, an extension of 120 days has been requested on the program.

I. INTRODUCTION

This program is a joint effort of the Owens-Corning Fiberglas Corp., the U.S. Polymeric Chemicals, Inc., and the Aerojet-General Corp. The program covers an 8-month period of two phases.

The purpose of this work is to develop an improved, preimpregnated material (prepreg) suitable for use in filament-wound motor cases capable of withstanding tensile-strength (fiber-stress) levels of 375,000 to 400,000 psi at room temperature and maintaining at least 75% of the room temperature strength at 300°F.

The contract provides that Phase I shall establish: (a) documented optimum procedures for the forming, processing, handling, and shipping of glass roving; (b) documented, optimized, controlled impregnation procedures with a suitable resin system for 300°F application; (c) reliable mechanical-property data (with correlation of strand, NOL ring composite, and 18-in.-dia subscale chamber test data); and (d) tentative material and process specifications for high-strength, high-quality, prepreg material.

The test results obtained with the optimum lot in Phase I are to be confirmed with a larger sample size in Phase II, in which the work is to be conducted under production conditions. Final material and process specifications will be written at the completion of Phase II.

II. PROGRAM STATUS

Lots 1 through 5 and Lot 7 of experimental roving have been received from Owens-Corning. Lots 1 through 5 have been completely evaluated in dry-glass and prepreg form, with the exception that 18-in.-dia chambers from Lots 4 and 5 prepreg have been wound but not tested. Lot 7 dry glass has been evaluated in strands and NOL rings and is presently at U.S. Polymeric for impregnation. An in-process 18 in.-dia chamber has been wound from this material and will be tested shortly. Lot 7 was a substitute lot and was intended to evaluate the effect of a relatively large negative change in filament diameter. The roving in this lot of material consists of approximately

408 filaments per end compared to 204 filaments per end for standard HTS roving. In all other respects this roving was equivalent to standard improved roving such as that evaluated in Lot 1 on this program. Lot 6, which was originally intended to evaluate improved catenary, was delayed because of the inability of Owens-Corning to improve this property beyond the improvement which resulted from process changes made for Lot 1. However, recently Owens-Corning indicated that a catenary improvement might be possible, and a lot incorporating the necessary process changes has been ordered. This catenary-free lot will be Lot 6, as designated in the original program.

Because of the delay in receiving materials, an extension to the program has been requested. This extension is for the purpose of allowing time to evaluate all experimental lots.

III. TEST RESULTS

Laboratory test data for all material evaluated thus far is given in Table 1 for dry glass and Table 2 for prepreg. Of the six experimental lots of dry glass evaluated, all the lots except Lot 2 have had an average strand tensile strength between 335,000 and 350,000 psi. The NOL ring strength has varied between about 320,000 and 335,000 psi for the five high-strength lots. The strand tensile strength of prepreg has been consistently lower than the equivalent dry glass by about 10%. However, the NOL ring strength of prepreg has been higher than the equivalent dry glass. In this property, Lot 5 had an average of 348,800 psi. This value is actually the highest value obtained in either strand or NOL ring testing during this program. An 18-in. chamber fabricated from Lot 2 prepreg was burst-tested and failed at a hoop filament stress of 297,700 psi. The highest chamber value obtained thus far is 333,000 psi for the chamber fabricated with Lot 3 prepreg. Table 3 summarizes the chamber data.

IV. STATISTICAL ANALYSIS

The original statistical analysis of dry glass strength data developed from the Aerojet strand test accounted for 38% of strength variability. This

analysis assumed a linear mathematical model. Recently a series of curvilinear mathematical models was tried, and 75% of the variation in tensile strength is accounted for by one of these models. The two most important variables as indicated by both the curvilinear and linear models are weight per yard and fuzz content. In particular, weight per yard appears to be a very sensitive variable, with a change of 0.01 g in this property, producing a change of 22,000 psi in tensile strength. It is important to note that the mathematical models can be expected to be accurate only within the actual range of values of the variables used in the analysis. Thus, the range of weight per yard used in the analysis was only from 0.639 to 0.666 g and it is possible that at a weight per yard of 0.61 or even 0.62 the effect may not be so pronounced. In Table 4 the variables are listed in order of descending importance. The optimum value for each variable as derived from the curvilinear model and the range of values used in the analysis are also shown in Table 4. The effect of solids content is not shown in Table 4. This is due to the fact that the computer curvilinear correlation program could handle only seven variables, and at least one of the variables had to be left out of these runs. Previous runs had indicated that solids content and volatile content were highly correlated to one another and it is felt that only one of these two variables is needed in the model. However, the solids content variable is being evaluated in subsequent computer runs.

The statistical evaluation of the data has been delayed somewhat because of errors in the computer output. It is anticipated that these errors will be corrected shortly, enabling a final prediction equation to be developed. The unimportant variables will be deleted from this equation.

V. TECHNICAL DISCUSSION

Figure 1 depicts a comparison of chamber, NOL ring, and strand tensile data. In addition to the chamber filament stress at burst, average NOL ring strength and average strand strength for the experimental and control roving, comparisons are shown between these properties. The latter data is

shown as the chamber strength divided by the NOL and strand strengths respectively; it is therefore a measure of the efficiency of chamber design and processing. Except for Chambers 0525-3 and 0525-4, which failed at low burst pressures, the efficiency ratios are between 0.9 and 1.0 for all chambers and between 0.95 and 1.05 for five of the ten chambers, for both the strand and NOL ring comparisons.

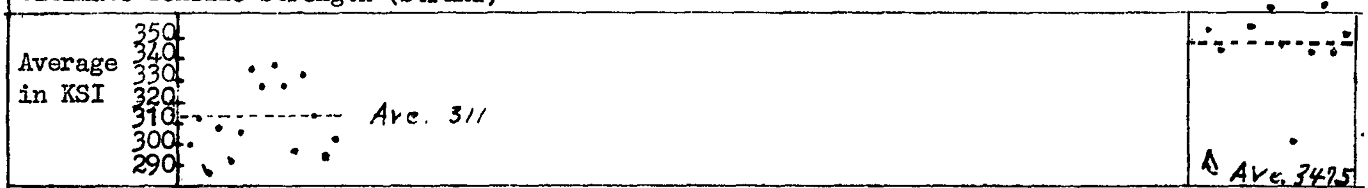
TABLE 1

EXPERIMENTAL ROVING (HTS) QUAL

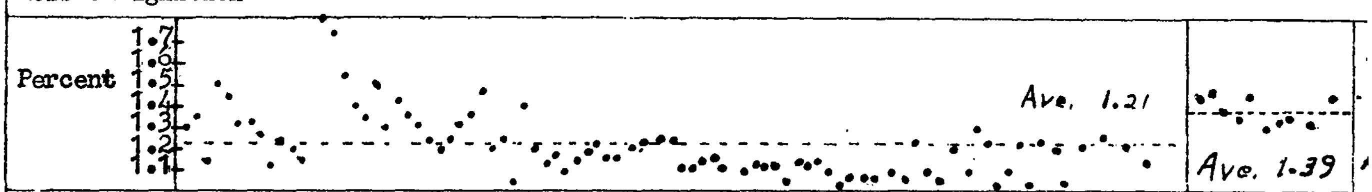
DRY ROVING

Lot No.	37 (Control)	1
Lab No.	1069	4027
Date	11 August 1961	10/10/61
Operator		

Ultimate Tensile Strength (Strand)



Loss on Ignition



Weight per Yard (Glass)

NOL Ring (Glass Stress)

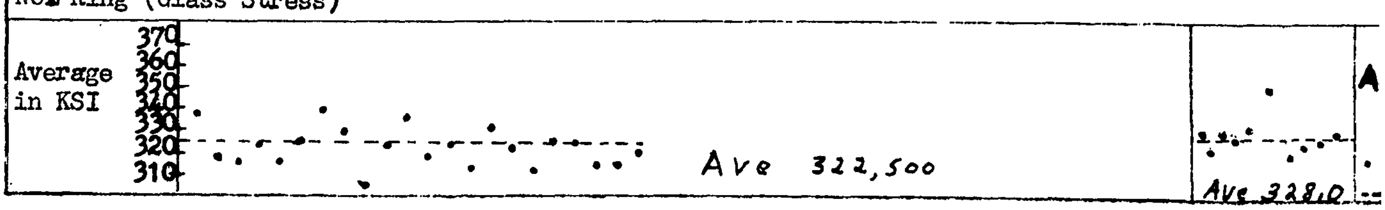


TABLE 1

NG (HTS) QUALITY CONTROL DATA

DRY ROVING

1	2	3	4	5	6	7	8	
4027		4027A						
10/10/61		11/14/61						
Ave. 3425	Ave. 307.2	Ave 342.0	Ave 339.4	Ave 346.8		Ave. 334.8		
Ave. 1.39	Ave 1.46	Ave. 1.44	Ave 1.44	Ave 1.53		Ave. 1.45		
Ave. 0.661	Ave. 0.652	Ave 0.649	Ave 0.651	Ave 0.648		Ave. 0.656		
Ave. 328.0	Ave. 304.6	Ave. 318.8	Ave. 333.8	Ave. 323.9		Ave. 322.8		

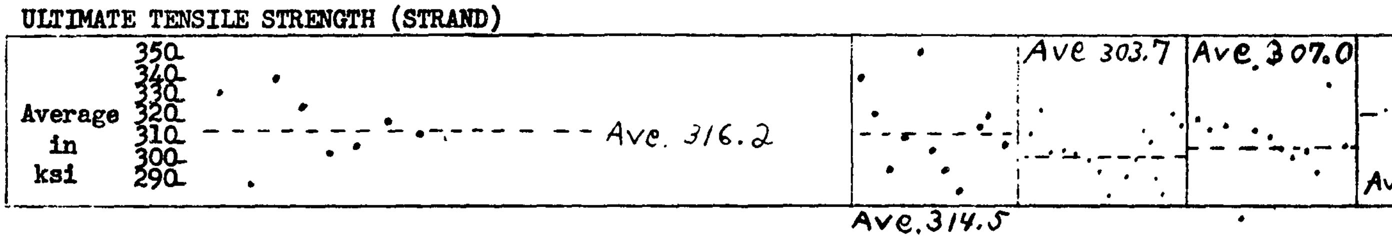
2

TABLE 2

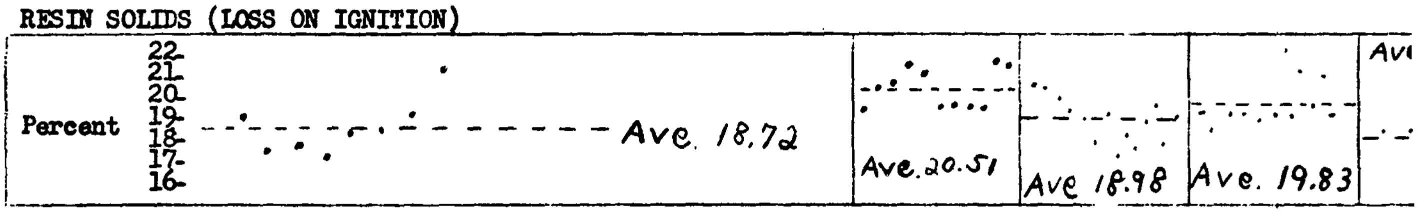
PRE-PREG QUALITY CONTROL
3-F 804

Lot No.	37-F758 (Control)	1-F794	2-F807	3-F804	4
Lab. No.					
Date					
Operator					

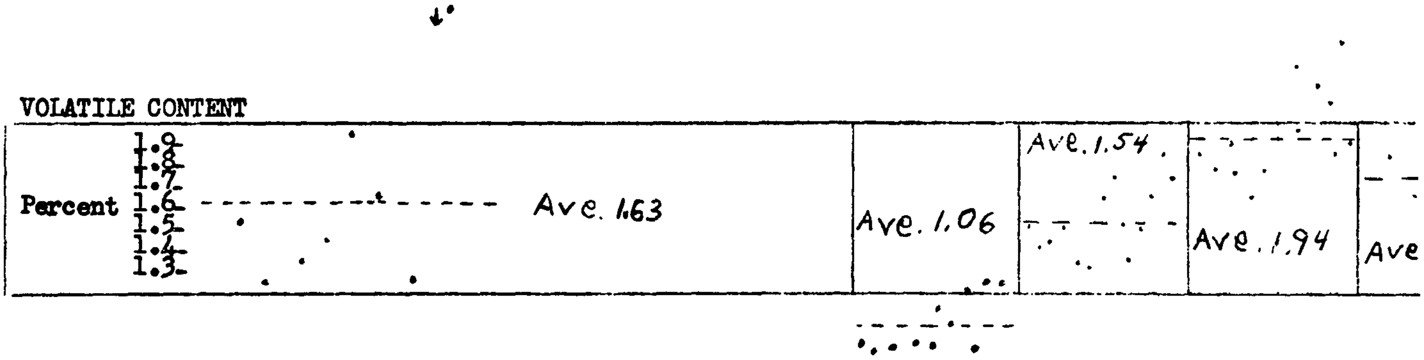
ULTIMATE TENSILE STRENGTH (STRAND)



RESIN SOLIDS (LOSS ON IGNITION)



VOLATILE CONTENT



NOL RING (GLASS STRESS)

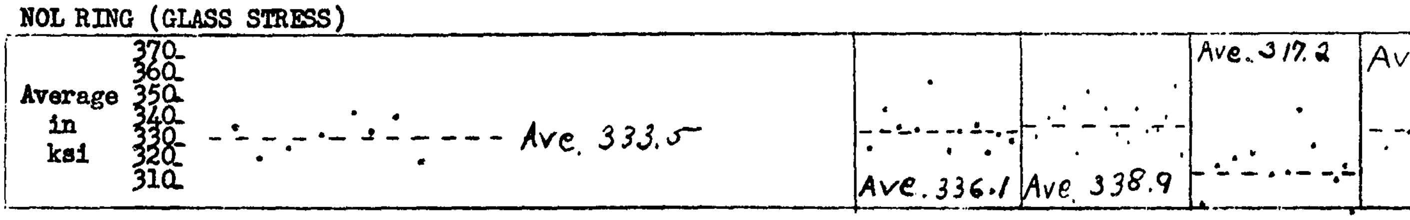


TABLE 2

PRE-PREG QUALITY CONTROL DATA

3-F 804

	1-F794	2-F807	3-F804	4-F826	5-F838			
.2	Ave. 314.5	Ave 303.7	Ave. 307.0	Ave. 322.7	Ave. 321.8			
3.72	Ave. 20.51	Ave 18.98	Ave. 19.83	Ave. 18.15	Ave. 19.36			
	Ave. 1.06	Ave. 1.54	Ave. 1.94	Ave. 1.76	Ave. 1.81			
	Ave. 336.1	Ave. 338.9	Ave. 317.2	Ave. 335.8	Ave. 348.8			

2

TABLE 3

18-INCH - DIAMETER FILAMENT WOUND CHAMBERS - TEST RESULTS

CHAMBER NUMBER	0050-163	0050-164	0525-3	0525-4	0525-5	0525-6	0525-7	0525-8	0525-9	0525-10	0525-11			
TEST DATE	9/7/61	9/11/61			12/4/61	12/4/61								
MATERIAL	20-E HTS Lot 37	20-E HTS Lot 37	20-E HTS Lot 1	20-E HTS Lot 37	20-E HTS Lot 1	20-E HTS Lot 3	20-E HTS Lot 2	20-E HTS Lot 4	20-E HTS Lot 5	20-E HTS Lot 3	20-E HTS Lot 2			
MATERIAL TYPE	Wet Winding	Wet Winding	Wet Winding	Pre-Preg (Lot F 758)	Pre-Preg (Lot 794	Wet Winding	Wet Winding	Wet Winding	Wet Winding	Pre-Preg Lot 804	Prepreg Lot			
NO. OFF-CENTER BOSSES	None	None	None	None	None	None	None	None	None	None	None			
DESIGN	CBO	CBO	CBO	CBO	CBO	CBO	CBO	CBO	CBO	CBO	CBO			
TEST PRESSURE (PSIG)	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min	400 psig for 1 min			
DESIGN BURST PRESSURE (PSIG)	800	800	800	800	800	800	800	800	800	800	800			
ACTUAL BURST PRESSURE (PSIG)	866	895	860	740	950	910	960	890	870	930	900			
BURST AREA	Cylinder	Cylinder	Cylinder	Cylinder	Cylinder	Cylinder	Cylinder	Cylinder	Cylinder	Cylinder	Cylinder			
TYPE OF FAILURE	Filament	Filament	Filament	Filament	Filament	Filament	Filament	Filament	Filament	Filament	Filament			
DIRECTION OF FAILURE	Hoop	Hoop	Hoop	Hoop	Hoop	Hoop	Hoop	Hoop	Hoop	Hoop	Hoop			
LONG. FILAMENT STRESS IN CYL. (KSI)	245.5	235.2	226.2	200.0	236.3	231.6	249.7	235.8	212.8	232.4	232.8			
HOOP FILAMENT STRESS IN CYL. (KSI)	305.9	311.2	267.1	260.0	297.8	306.9	322.1	294.1	307.8	333.3	297.7			
LONG. COMPOSITE STRESS IN CYL. (KSI)	63.6	63.3	56.7	52.1	60.4	62.2	66.1	60.5	60.3	63.4	59.4			
HOOP COMPOSITE STRESS IN CYL. (KSI)	127.2	126.6	113.4	104.2	120.8	124.4	132.2	121.0	120.6	126.8	118.8			
LONG. FILAMENT STRESS IN HEAD (KSI)	245.5	235.2	226.2	200.0	236.3	231.6	249.7	235.8	212.8	232.4	232.8			
LONG. COMPOSITE STRESS IN HEAD (KSI)	165.7	158.8	152.7	132.2	156.2	156.1	168.5	159.2	143.6	153.6	153.9			
REMARKS	Chamber 0050-163 was fabricated from a spool of roving which exhibited an average ultimate tensile strength (Strand test) of 297,000 psi.	Chamber 0050-164 was fabricated from a spool of roving which exhibited an average ultimate tensile strength (Strand test) of 337,000 psi	Strand = 363,700 psi NOL = 320,500 psi	Strand = 333,300 psi NOL = 323,000 psi	Strand = 311,130 psi NOL = 337,100 psi	Strand = 333,300 psi NOL = 297,800 psi	Strand = 285,250 psi NOL = 323,400 psi	Strand = 344,400 psi NOL = 324,000 psi	Strand = 355,730 psi NOL = 321,000 psi	Strand = 338,050 psi NOL = 318,500 psi	Strand = 292,150 psi NOL = 344,900 psi			

TABLE 4

OPTIMUM VALUES OF PROCESS VARIABLES
IN DESCENDING ORDER OF IMPORTANCE

Variable	Optimum Value	Actual Range of Values Low	High
Weight per yard (g)	0.639	0.639	0.666
Fuzz content (g)	0.00000	0.00000	0.00360
Wet-out rate (dimensionless units)	87.19	81.50	93.75
Volatile content (wt %)	0.284	0.009	0.278
Stiffener (in.)	2.86	3.00	4.10
Ignition Loss (wt %)	1.99	0.78	2.48
Package hardener (dimensionless units)	66.9	60.0	77.5

COMPARISON OF AVERAGE STRAND AND NOL RING DATA WITH CHAMBER DATA

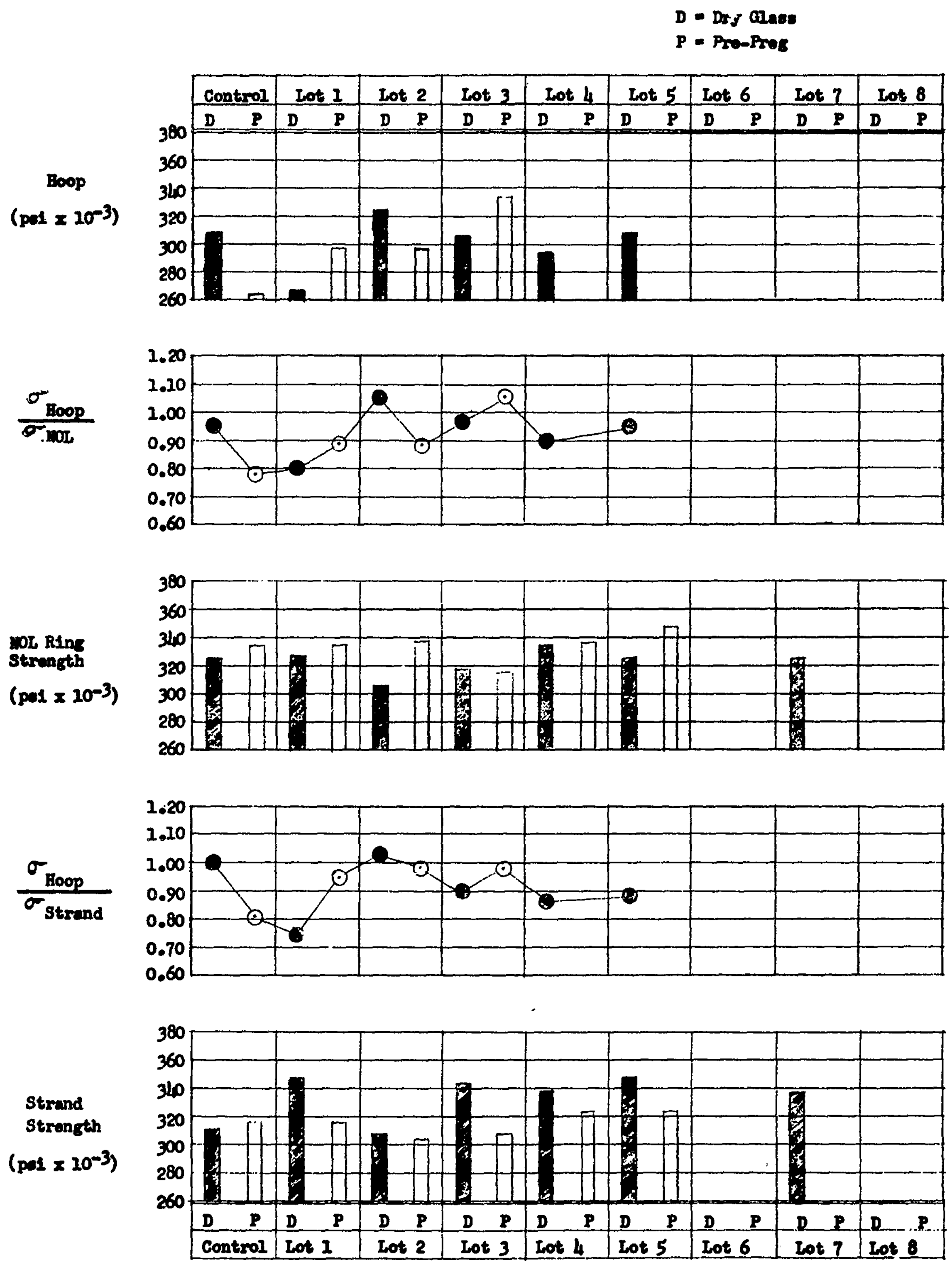


Figure 1

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